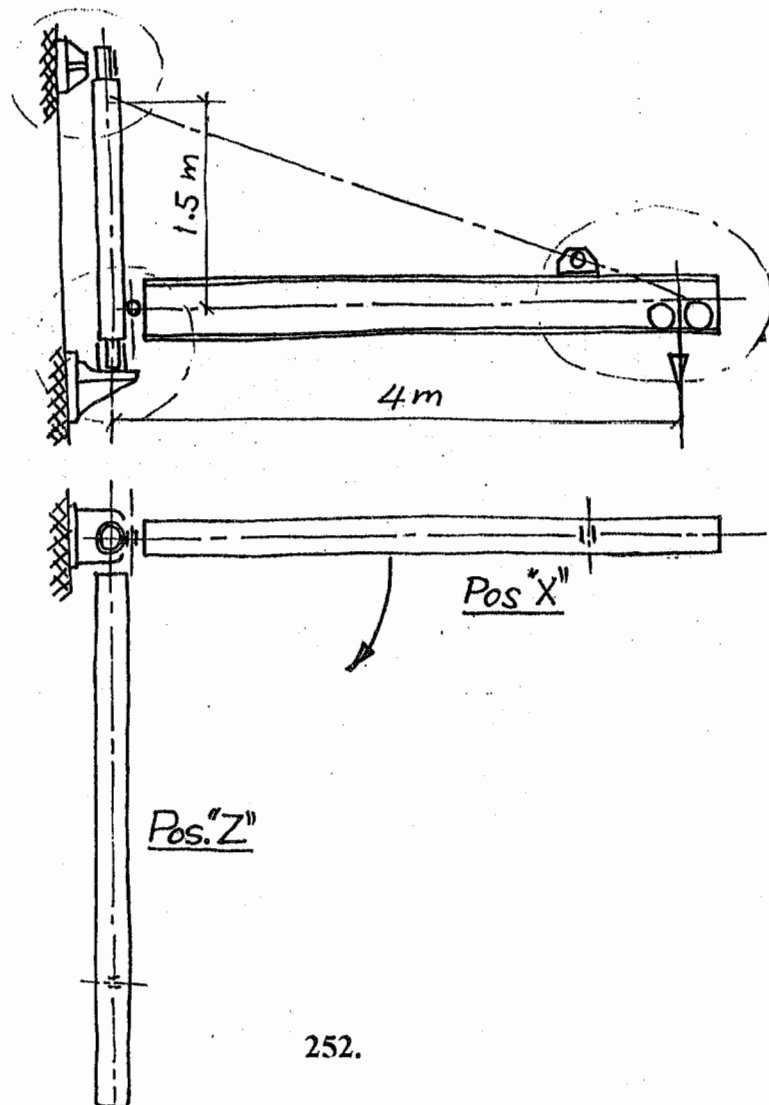


Wall Jib-Crane [S.W.L. 15 kN, 4 m reach]

Attached are the principal design calculations for a wall jib crane S.W.L. 15 kN, 4 m. reach when the beam is in Pos "X".

Guided by the sketches, diagrams, calculations, assumptions and the selected materials of different items and parts, it is required to:

- 1- Check the wall brackets fixation, dimensions and select the suitable material when the crane is in Pos "X".
- 2- Construct the encircled zones giving all the details and showing the trolley at the two extreme load positions on the beam.



15 kN, 4 m outreach Jib Crane.

S.W.L. = 15 kN

Required, I-beam Size:

Three positions of loading along the beam should be considered; namely I, II, III

Two test conditions:

1) static loads

(1-1) Test load = 1.4 S.W.L.

in position (II), Successful

if δ = beam deflection is less than $\frac{1}{700} \times$ loaded span

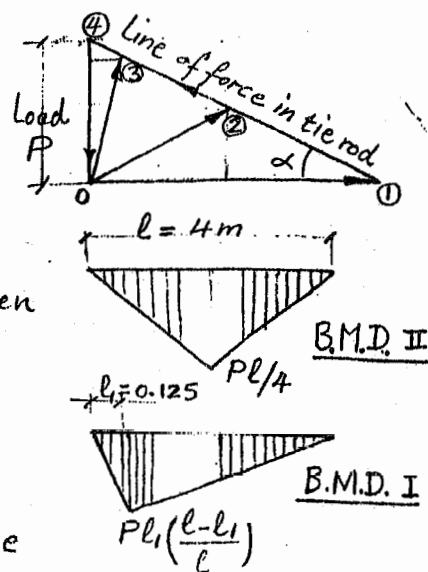
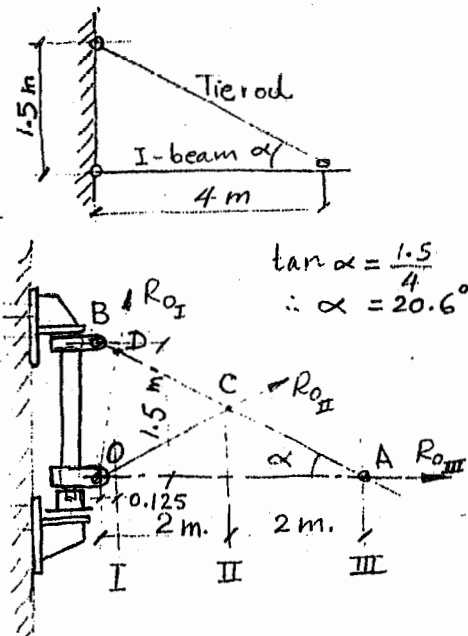
taking into consideration the self weight values.

(1-2) Test Load = 1.2 S.W.L.

in position (I), to check that no relative displacement between supports occurs.

(1-3) Test load = 1.2 S.W.L.

in position (III), "OA" should be horizontal. If "A" gets below horizontal, correction should be done using the turn-buckle located on the tie rod.



The three cases of static loading represent the technique of checking the structure integrity.

Bending stresses in the I-beam:

$$1) \text{ B.M. at test} = Pl/4 = \frac{21 \times 4}{4} = 21 \text{ kN.m}$$

$$\sigma_b = \frac{M}{Z_{xx}} = \frac{21 \times 10^6}{278000} = 75.5 \text{ N/mm}^2$$

Material: Structural st 37, $\sigma_{yt} = 200 \text{ N/mm}^2$

$$\text{margin of safety at test} = 2.65 > 1.2$$

$$2) \text{ B.M. due to SWL} = \frac{15 \times 4}{4} = 15 \text{ kN.m.}$$

$$\sigma_{b_{\text{SWL}}} = \frac{15 \times 10^6}{278000} = 54 \text{ N/mm}^2$$

$$\text{margin of safety at SWL} = \frac{200}{54} = 3.7$$

Force Analysis:

There are three joints "O", "A", "B".

The carried wt. is always vertical, the force along AB is always tension in the direction of the tie rod and the reaction through "O" always pass through the point of intersection between the line of action of the carried wt. and the line of action of the tie rod tension.

Three cases will be examined:

$$\text{at test load} = 1.4 \text{ SWL. Pos. II}$$

$$\text{at test load} = 1.2 \text{ SWL. Pos. I \& III}$$

$$\text{at SWL.} = 15 \text{ kN Pos I, II, III}$$

Note: Pos. I is only 0.125 m from O while the full span is 4 m. Hence, consider the load at Pos. I is directly on the hinge. The 0.125 m is half the length of the trolley.

at static test

$$M_{B_{\text{test}}} = 21 \text{ kN.m}$$

$$\sigma_{b_{\text{test}}} = 75.5 \text{ N/mm}^2$$

$$\text{margin} = 2.65$$

at SWL.

$$M_{B_{\text{SWL}}} = 15 \text{ kN.m.}$$

$$\sigma_{b_{\text{SWL}}} = 54 \text{ N/mm}^2$$

$$\text{margin} = 3.7$$

2) Dynamic loads:

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The dynamic test load = 1.2 S.W.L.

This test represents a check for the integrity of the lifting appliance.

After tests, when successfully carried out, the appliance is adjusted to tripout if the gets in excess of S.W.L.

OA is a simple beam,

$$\delta = \frac{Pl^3}{48EI} \quad \text{i.e.} \quad \frac{\delta}{l} = \frac{Pl^2}{48EI_{xx}}$$

$$\frac{\delta}{l} \leq \frac{1}{700}, \quad P_0 = 1.4 * 15 = 21 \text{ kN}$$

$$l = 4000 \text{ mm}, E = 2.1 * 10^5 \text{ N/mm}^2$$

$$\frac{\delta}{l} \leq \frac{1}{700}$$

$$P = 21 \text{ kN}$$

$$\therefore I_{xx} \geq \frac{21 * 10^3 * (4000)^2}{48 * 2.1 * 10^5 * (1/700)} \geq 23.3 * 10^6 \text{ mm}^4$$

$$I_{xx} \geq 2330 \text{ cm}^4$$

The nearest are:

$$I_{20} \rightarrow I_{xx} = 2140 \text{ cm}^4$$

$$I_{22} \rightarrow I_{xx} = 3060 \text{ cm}^4$$

$$I_{24} \rightarrow I_{xx} = 4250 \text{ cm}^4$$

Selected size

I22

Properties of I22 :

$$\frac{220 * 98}{8.1 * 12.2}, I_{xx} = 3060 \text{ cm}^4, Z_{xx} = 278 \text{ cm}^3$$

$$I_{yy} = 162 \text{ cm}^4, Z_{yy} = 33.1 \text{ cm}^3$$

$$wt = 31.1 \text{ kg/m}, A = 39.5 \text{ cm}^2$$

Expected deflection at Static test :

$$\delta^* \approx \frac{21 * 10^3 * (4000)^3}{48 * 2.1 * 10^5 * 3060 * 10^4} \approx 4.36 \text{ mm}$$

$$\frac{\delta^*}{l} = 1/918 < \frac{1}{700}$$

$$\frac{\delta}{l} \approx \frac{1}{918}$$

Note:

δ^* is considered approximate since the self weight is not included. Try to calculate the actual value by accounting for beam weight and the trolley weight

Acting Load & Load Condition	Point of Action	Pos. I			Pos. II			Pos. III		
		R	R _x	R _y	R _{kN}	R _x	R _y	R _{kN}	R _x	R _y
unit load 1 kN	A	Z	Z	Z	1.424	1.33	0.5	2.85	2.67	1.0
	B									
	O	1.0	Z	1.0	1.424	1.33	0.5	2.67	2.67	Z
Static load = SWL * 1.4 = 21 kN	A				29.9	27.93	10.5			
	B									
	O				29.9	27.93	10.5			
1.2 * SWL = 18 kN	A	Z	Z	Z	25.63	23.94	9.0	51.3	48.06	18
	B									
	O	18.0	Z	18.0	25.63	23.94	9.0	48.06	48.06	Z
SWL = 15 kN	A	Z	Z	Z	21.36	19.95	7.5	42.75	40.05	15
	B									
	O	15.0	Z	15.0	21.36	19.95	7.5	40.05	40.05	Z

Tie rod size:

From the tabulated values the maximum load on the tie rod occurs when testing with $1.2 * \text{SWL}$. load at position III. Hence, the tie rod and the connections at "A" and "B" should be calculated for :

max. load = 51.3 kN acting along the tie rod centerline.

The critical section is the core area of the Lefthand or Righthand threads in connection with the turnbuckle. When adjusting the beam level under load, this core area is subjected to:

$$P_a \text{ (tension)} = 51.3 \text{ kN}$$

$$P_a = 51.3 \text{ kN}$$

$$T = 2T_1 = \left[P_a \frac{d_m}{2} \left(\frac{\tan \alpha + \mu'}{1 - \mu' \tan \alpha} \right) \right] * 2$$

Size	M16x1.5	M18x1.5	M20x1.5	M22x1.5	M24x1.5
d_i (mm)	14.052	16.052	18.052	20.052	22.052
A_c (mm ²)	155	202	256	316	382
$d_m = \frac{d_i + d_o}{2}$ (mm)	15	17	19	21	23
$\tan \alpha = \frac{p}{\pi d_m}$	0.032	0.028	0.025	0.023	0.021
$\tan \alpha + \mu' = X$	0.263	0.259	0.256	0.254	0.252
$X \cdot d_m = Y$ (mm)	3.945	4.403	4.864	5.334	5.796
$T = P_a \cdot Y$ (N.m)	202	226	250	274	297
τ (N/mm ²)	371	271	216	173	141
$\sigma = \frac{P_a}{A_c}$ (N/mm ²)	331	254	200	162	134
$\tau_c = \frac{1}{2} \sqrt{\sigma^2 + 4\tau^2}$	406	299	238	191	156
$\sigma_y \geq$	812	598	476	382	312
Material	50CrV4 257.	(34Cr4) 37Cr4	(StC55) St.C60	St 52-3 St.C45	St 52-3 St C35

$$\mu = 0.2$$

$$\mu' = \frac{\mu}{\cos \beta} = 0.231$$

$$1 - \mu' \tan \alpha \approx 1$$

$$\text{margin} = 1.2$$

$$\text{St 52-3}$$

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Notes:

1) Materials bracketed have σ_y less than the required min. σ_y within 5% which is acceptable.

2) Selecting st. 52-3 is based on utilizing a cheap material since hardness and wear resistance are not functional.

For st. 52-3 :

$$16 < \phi \leq 40$$

$$\sigma_{yt} = 345 \text{ N/mm}^2$$

Forces on the post:

Refer to table of forces acting at each position and find out that the extreme reactions on the post occur at a test load = 18 kN in pos. III :

- Tension in tie rod = 51.3 kN at B

$$\left[\begin{array}{l} \text{horizontal component} = 48.06 \text{ kN} \\ \text{Vertical component} = 18.0 \text{ kN} \end{array} \right]$$

$$F_{\text{Tie Rod}} = 51.3 \text{ kN}$$

- Reaction at O = 48.06 kN in horizontal direction.

$$R_O = 48.06 \text{ kN.}$$

Reactions on the wall at B₁ and O₁ are

$$R_{B_1} = \frac{1}{(0.25 + 1.5 + 0.25)} [48.06 * 1.75 - 48.06 * 0.25]$$

$$\therefore R_{B_1} = \overleftarrow{36.045} \text{ kN}$$

$$R_{B_1} = \overleftarrow{36.045} \text{ kN}$$

$$R_{O_1} = \frac{1}{2} [48.06 * 1.75 - 48.06 * 0.25]$$

$$= \overrightarrow{36.045} \text{ kN}$$

$$R_{O_1} = \overrightarrow{36.045} \text{ kN}$$

Maximum BM = 9.01 kN.m.

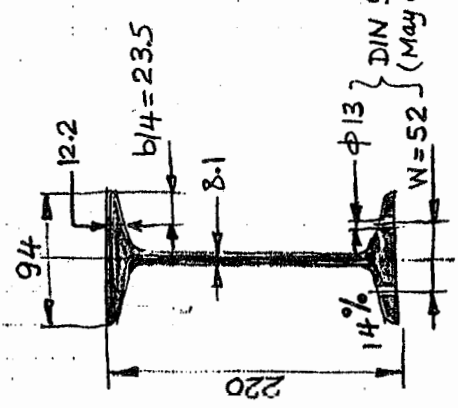
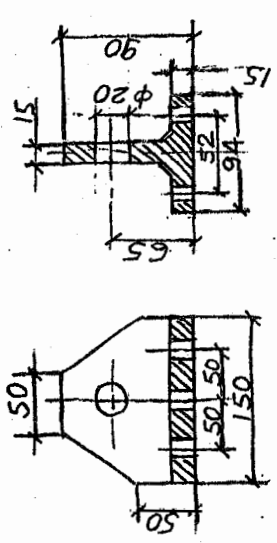
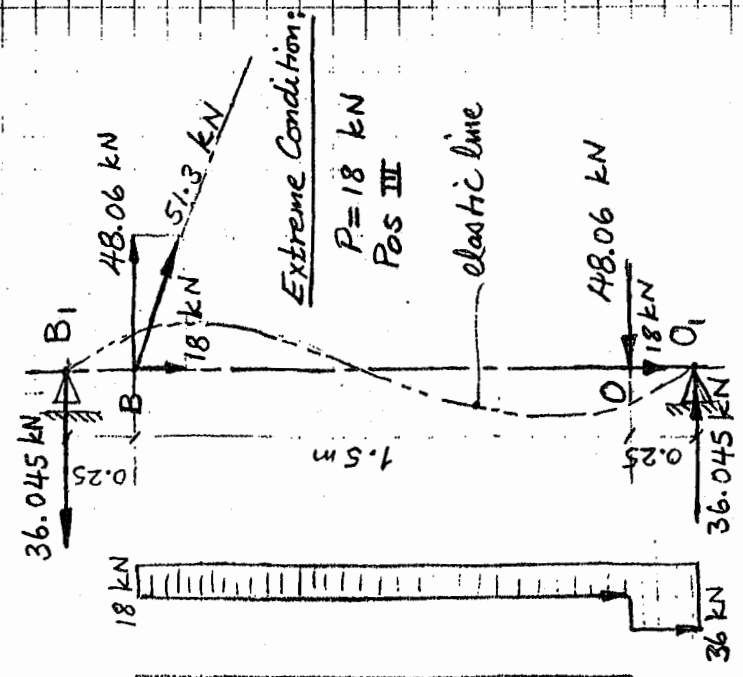
$$BM_{\text{max}} = 9.01 \text{ kN.m}$$

Post material is st 42, $\sigma_y = 220 \text{ N/mm}^2$
margin of safety = 1.5 (to have some rigidity)

Material
st 42

$$\therefore \frac{220}{1.5} = \frac{9.01 * 32 * 10^6}{\pi D^3}$$

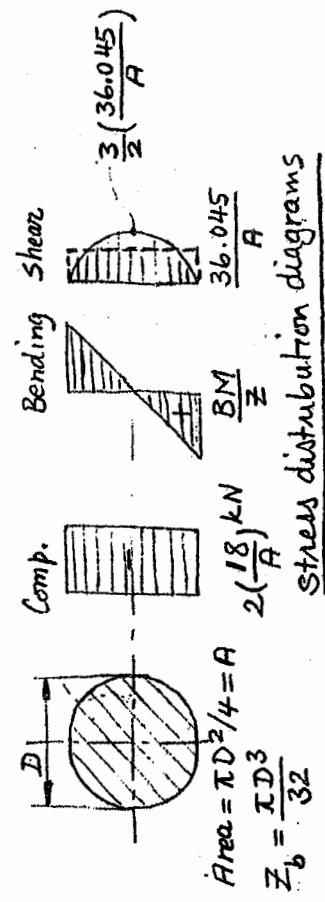
Loading diagrams



Axial loads

SF.D.

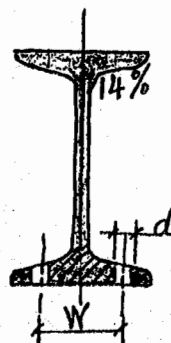
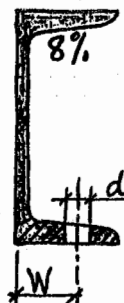
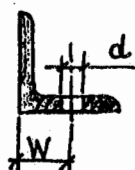
BN.D.



$$\text{Area} = \pi D^2/4 = A$$

$$Z_b = \frac{\pi D^3}{32}$$

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[DIN 997 May 1963]

DIN 996 (April 1927)

Equal Angles

I

Size	W	d	W	d	Nominal Size	W	d
3	17	8.5	20	11	4		
4	22	11	25	11	6 1/2		
5	30	14	25	14	8	[22]	[6.4]
6	35	17	30	14	10	[28]	[6.4]
7	40	20	30	17	12	[32]	[8.4]
8	45	23	35	17	14	34 [34]	11 [11]
9	50	26	36	20	16	38 [40]	14 [11]
10	55	26	40	20	18	44 [44]	14 [13]
			40	23	20	46 [48]	17 [13]
			45	23	22	52 [52]	17 [13]
			45	26	24	56 [56]	17 [17]
			50	26	26	58 [60]	20 [17]
			50	26	(28)	62	20
			55	26	30	64	20
			55	26	(32)	70	20
			55	26	36	74	23
			55	26	(38)	80	23
			60	26	40	84	23

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$$\therefore D = 85.5 \text{ mm}$$

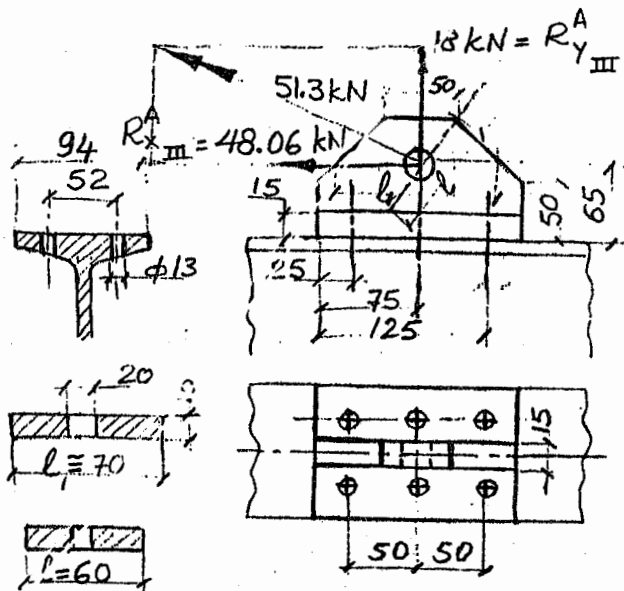
This value represents the min. shaft diam.

$$D \geq 85.5 \text{ mm}$$

post

Design of Joints:

1) Tie rod - carrying beam connection:



(1-1) Pin diameter:

Calculated for double shear:

$$\tau = \frac{51.3 \times 10^3}{2A} = \frac{2 \times 51.3 \times 10^3}{\pi d^2}$$

$$\tau = 0.6 \sigma_y / 1.2 = \sigma_y / 2 \quad \therefore d = \sqrt{\frac{2 \times 2 \times 51.3 \times 10^3}{\pi \sigma_y}}$$

material	st 37	st 42	st 50
σ_y (N/mm ²)	200	220	250
$d \geq$ (mm)	18.1	17.2	16

Pin diameter is taken 20 mm (h_{II})
Select basic shaft system h_{II}/H_{II}

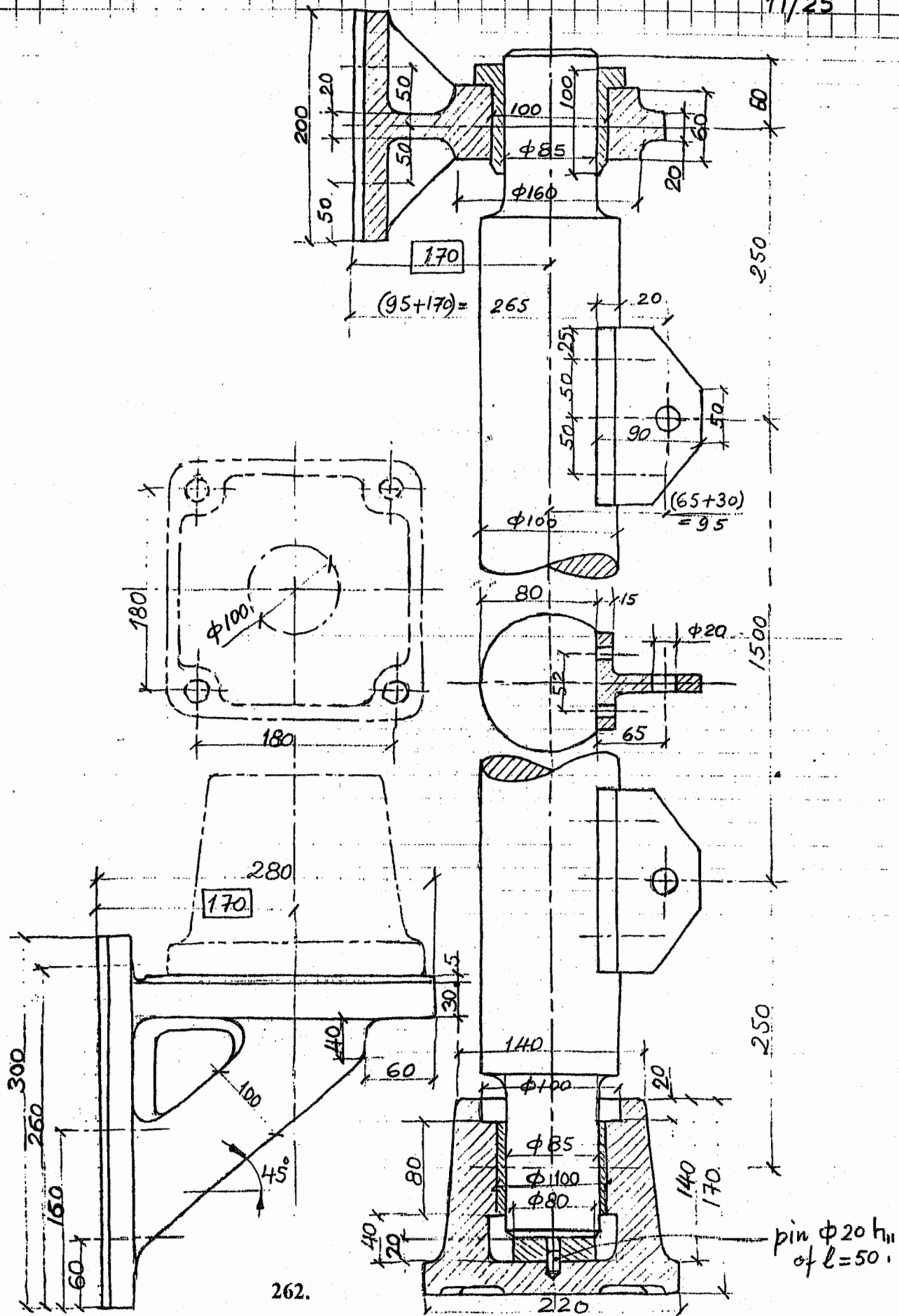
$$R_{III}^A = 51.3 \text{ kN}$$

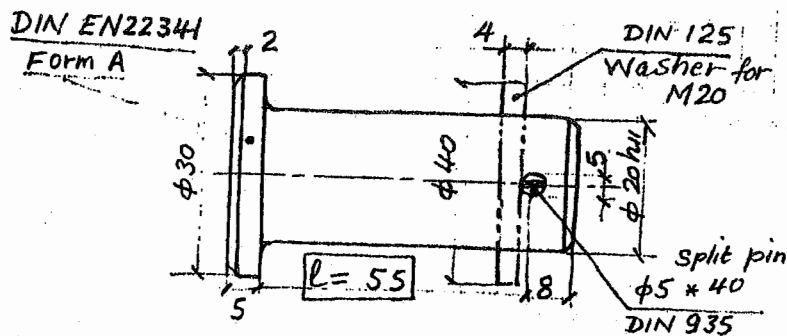
Material:
st 37

$$d = 20 \text{ mm}$$

h_{II}/H_{II}

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(1-2) Bracket Web:

Selected thickness is checked for crushing.

$$\sigma_{cr} = \frac{R_{III}^A}{d b} = \frac{51.3 \times 10^3}{20 \times 15} = 171 \text{ N/mm}^2$$

$$\text{margin of safety} = \frac{\sigma_y}{\sigma_{cr}} = \frac{200}{171} = 1.17$$

$$\sigma_{cr} = 171 \text{ N/mm}^2$$

Note:

$\sigma_{cr} = (400 \times \text{BHN} - 10,000) \text{ lb/in}^2$ is an imperial formula for annealed carbon steel. in SI. units:

$$\sigma_{cr} = \frac{400 \times \text{BHN} - 10,000}{145.037}$$

$$(1 \text{ lb/in}^2 \equiv 145.037 \text{ N/mm}^2)$$

for St 37, BHN = 100-130 i.e. min. BHN = 100

$$\therefore \sigma_{cr} = \frac{400 \times 100 - 10,000}{145} = 207 \text{ N/mm}^2$$

$$\therefore \text{the margin of safety} = \frac{207}{171} = 1.21$$

$$\text{margin} = 1.21$$

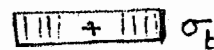
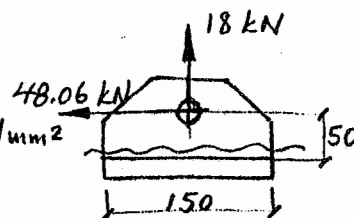
(1-3) Flange-Web connection:

$$\sigma_b = \frac{48.06 \times 10^3 \times 50 \times 6}{15 \times (150)^2} = 42.7 \text{ N/mm}^2$$

$$\sigma_E = \frac{18 \times 10^3}{15 \times 150} = -16 \text{ N/mm}^2$$

$$\sigma_{\text{tor max}} = 8 + 42.7 = 50.7 \text{ N/mm}^2$$

$$\sigma_{\text{tor min}} = 8 - 42.7 = -34.7 \text{ N/mm}^2$$



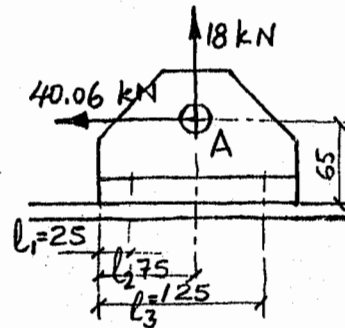
$$\sigma_b_{\text{max}} = 50.7 \text{ N/mm}^2$$

(1-4) Holding down bolts:

DIN 99 recommends hole diameter $\phi 13$ mm i.e. the suitable bolt size is 12 mm diam. Six bolts M12 x 1.25 of high tensile steel. The high tensile bolt grade of steel to be calculated.
Core area = 92.1 mm^2

6 M12 x 1.25 mm

At the loading condition in load Pos III, a residual load estimated at 30% and will be applied to the calculated max. load per bolt.



$$F_{\text{res.}} = 30\% F_{\text{tot}}$$

Bracket "A"

a) the vertical load:

$$\text{Force per bolt} = \frac{18}{6} = 3 \text{ kN}$$

$$F_v = 3 \text{ kN}$$

b) tension due to horizontal component:

$$2F_1/l_1 = 2F_2/l_2 = 2F_3/l_3$$

$$\frac{2F_1}{25} = \frac{2F_2}{75} = \frac{2F_3}{125} \text{ i.e. } F_1 = \frac{F_2}{3} = \frac{F_3}{5}$$

$$\begin{aligned} \text{also: } 40.06 \times 65 &= 2F_1 l_1 + 2F_2 l_2 + 2F_3 l_3 \\ &= 2\left(\frac{F_3}{5}\right) \times 25 + 2\left(\frac{3F_3}{5}\right) \times 75 + 2F_3 \times 125 \\ &= (10 + 90 + 250) F_3 = 350 F_3 \end{aligned}$$

$$\therefore F_3 = \frac{40.06 \times 65}{350} = 7.44 \text{ kN}$$

$$F_3 = 7.44 \text{ kN}$$

$$F_2 = 4.46 \text{ kN}$$

$$F_1 \approx 1.5 \text{ kN}$$

c) Shearing Force:

$$F_s = 40.06 \text{ kN.}$$

$$F_{\text{shear}} = 40.06 \text{ kN}$$

$$F_{\text{tot (normal)}} = F_v + F_3 = 3 + 7.44 = 10.44 \text{ kN/bolt}$$

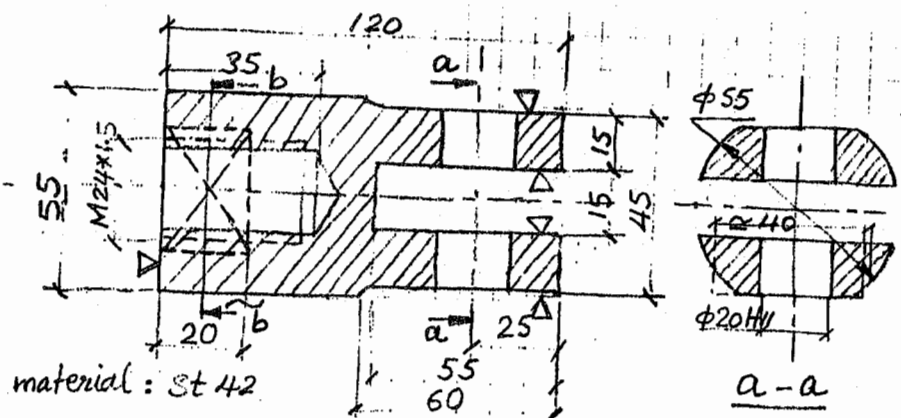
$$F_{\text{tot}} = 10.44$$

$$P_{\text{axial}} / \text{bolt} = 10.44 \text{ kN}$$

$$\& P_{\text{max}} = 10.44 \times 1.3 = 13.572 \text{ kN./bolt}$$

$$P_{\text{max}} = 13.572$$

2) Tie-rod forked connection:

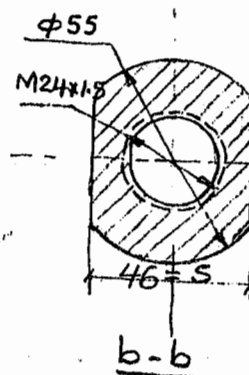


Load = 51.3 kN
section a-a is critical

$$\text{area} \approx 2[15 \times 40 - 15 \times 20] \\ \approx 600 \text{ mm}^2$$

$$\sigma_t = \frac{51.3 \times 10^3}{600} = 85.5 \text{ N/mm}^2$$

$$\text{margin of safety} = \frac{\sigma_y}{\sigma_t} = \frac{200}{85.5} \\ = 2.34$$



Mat. St 42
 $\sigma_y = 200 \text{ N/mm}^2$
 $P = 51.3 \text{ kN}$

$\sigma_t = 85.5 \text{ N/mm}^2$
margin = 2.34

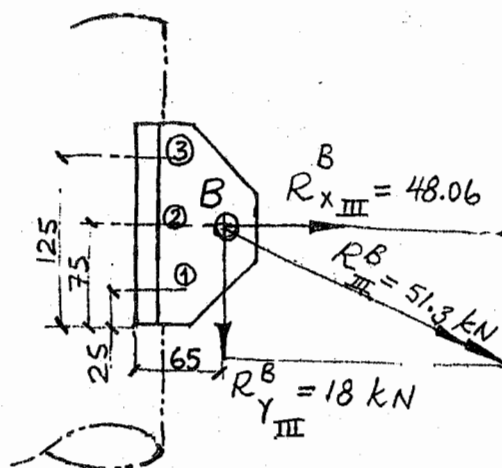
The same applies to the Forked end at "B"

③ Joint at "B":

The vertical component
is 18 kN:

$$F_3^B, F_2^B, F_1^B$$

are expected to be less
than those at "A"



Since:

$$2F_1/l_1 = 2F_2/l_2 = 2F_3/l_3$$

i.e also: $F_1 = \frac{F_2}{3} = \frac{F_3}{5}$

and $18 \times 65 = 2F_1^B \cdot l_1 + 2F_2^B \cdot l_2 + 2F_3^B \cdot l_3$

$$= 350 F_3^B$$

$$\therefore F_3^B = \frac{18 \times 65}{350} = 3.343 \text{ kN}$$

$$F_{\text{horiz}} = \frac{48.06}{6} = 8.01 \text{ kN/bolt}$$

$$F_{\text{axial}}^B / \text{bolt} = 3.343 + 8.01 = 11.353 \text{ kN}$$

Per bolt:

$$F_3^B = 3.343 \text{ kN}$$

$$F_{\text{horiz}} = 8.01 \text{ kN}$$

$$F_{\text{axial}}^B = 11.353 \text{ kN}$$

The shearing force = 18 kN is carried by the shaft shoulder.

The tie-rod forked end at "B" is the same one used at "A" and the pin diam. and details also are the same.

④ Joint at "O":

Due to $R_{YI}^O = 18 \text{ kN}$,

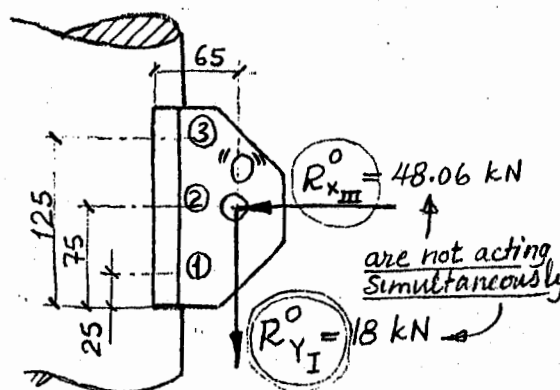
$$F_3^O = 3.343 \text{ kN}$$

While $R_{x_{III}}^O = 48.06 \text{ kN}$

pressing the bracket against the shaft releases the bolts free unless an axial load in the bolt due to initial

assembly load is in excess of the share of each bolt

i.e. $P_{\text{axial}}^O > \frac{48.06}{6} > 8.01 \text{ kN}$



$$F_3^O = 3.343 \text{ kN}$$

$$P_{\text{a}}^O > 8.01 \text{ kN}$$

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(4-2) I-beam holding plates:

This joint on the I-beam web comprises:

- two shouldered plates.
- two shear pins.
- two clamping bolts.

and there are two max. loads:

a) $R_{x_{III}}^0 = 48.06 \text{ kN}$, a horizontal force when test load is in pos. III. This force is transmitted to the shear pin at "O" through two shoulders.

$$R_{x_{III}}^0 = 48.06 \text{ kN}$$

$$\sigma_{cr} = \text{force / crushed area} = \frac{48.06 \times 10^3}{2(150)(22-18.5)} \approx 48 \text{ N/mm}^2$$

$$\text{i.e. } \sigma_{cr} = 48 \text{ N/mm}^2 < (\sigma_y / 1.2)_{st37}$$

$$\sigma_{cr} = 48 \text{ N/mm}^2$$

b) $R_{y_I}^0 = 18 \text{ kN}$, a vertical force when test load is in pos. I. This force is transmitted to the holding plates through two shear pins (and secured by the tightening of two through bolts selected to be M12 * 1.25).

$$R_{y_I}^0 = 18 \text{ kN}$$

$$\tau = \frac{18 \times 10^3}{2 \left[2 \times \frac{\pi}{4} (d^2) \right]}, \quad \tau \leq \frac{\tau_y \text{ st 37}}{1.2} \leq \frac{190 \times 0.6}{1.2}$$

$$\therefore d = \sqrt{\frac{18 \times 10^3 \times 1.2}{\pi \times 190 \times 0.6}} = 7.77 \text{ mm (for shear)}$$

$$\sigma_{cr} = \left(\frac{18 \times 10^3}{2} \right) / (8.1 \times d) \leq \frac{190}{1.2}$$

$$\therefore d \geq 7.02 \text{ mm (for crushing)}$$

The shear pin is taken $d = 10 \text{ h}_{11} \text{ mm}$ Note:

For the sake of unification, the two clamping bolts are taken M12 x 1.25 mm, $l = 45 + V_2 = 45 + \left[\frac{14}{16} \right] = 60 \text{ mm}$

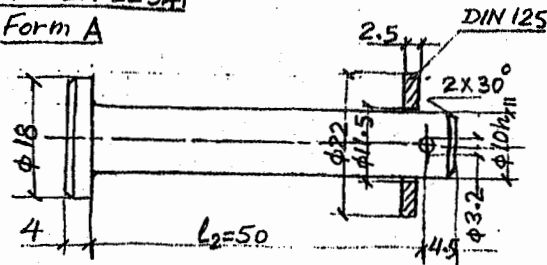
2 Shear pins

$$d = 10 \text{ h}_{11} \text{ mm}$$

$$l_2 \geq 50 \text{ mm}$$

2 bolts M12 x 1.2
with ordinary
washer & nut,
 $l = 60 \text{ mm}$

18/25

DIN-EN 22341
Form A

5) Pre-stressed bolts:

5-1) At Joint "A":

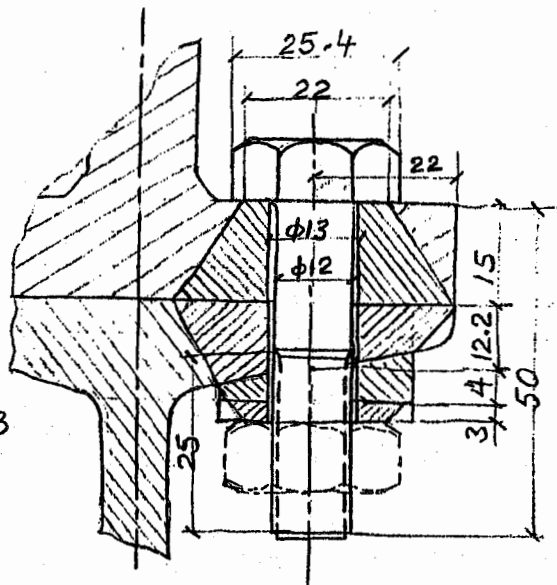
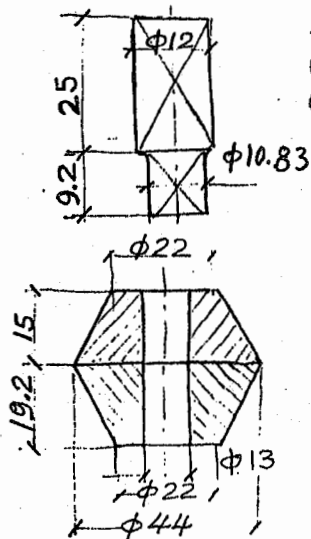
For M12x1.25:

Core area = 92.1 mm²

$$\therefore d_c = 10.83 \text{ mm}$$

$$d_m = 11.414 \text{ mm}$$

$$\tan \alpha = \frac{p}{\pi d_m} = 0.035$$



$$\frac{1}{C_b} = \frac{1}{E} \left[\frac{25 \times 4}{\pi (12)^2} + \frac{9.2 \times 4}{\pi (11.414)^2} \right]$$

$$\therefore C_b = 6.754 \times 10^5 \text{ N/mm}$$

$$\text{approximated } \frac{1}{C_J} = \frac{1}{E} \left[\frac{\frac{4}{\pi} \times 15}{\left(\frac{22+44}{2} \right)^2 - 13^2} + \frac{\frac{4}{\pi} \times 19.2}{\left(\frac{22+44}{2} \right)^2 - 13^2} \right]$$

$$\therefore C_J \approx 44.4 \times 10^5 \text{ N/mm}$$

$$\frac{C_J}{C_b} = 6.6, P_r = 0.3 P_{\text{ext}}, F_{\text{axial}}^B = 11.353 \text{ kN}$$

$$\therefore \text{Consider } P_i = P_{\text{ext}} + P_r = F_{\text{axial}}^B \times 1.3 = 14.8 \text{ kN}$$

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M12x1.25

$$d_c = 10.83 \text{ mm}$$

$$d_m = 11.414 \text{ mm}$$

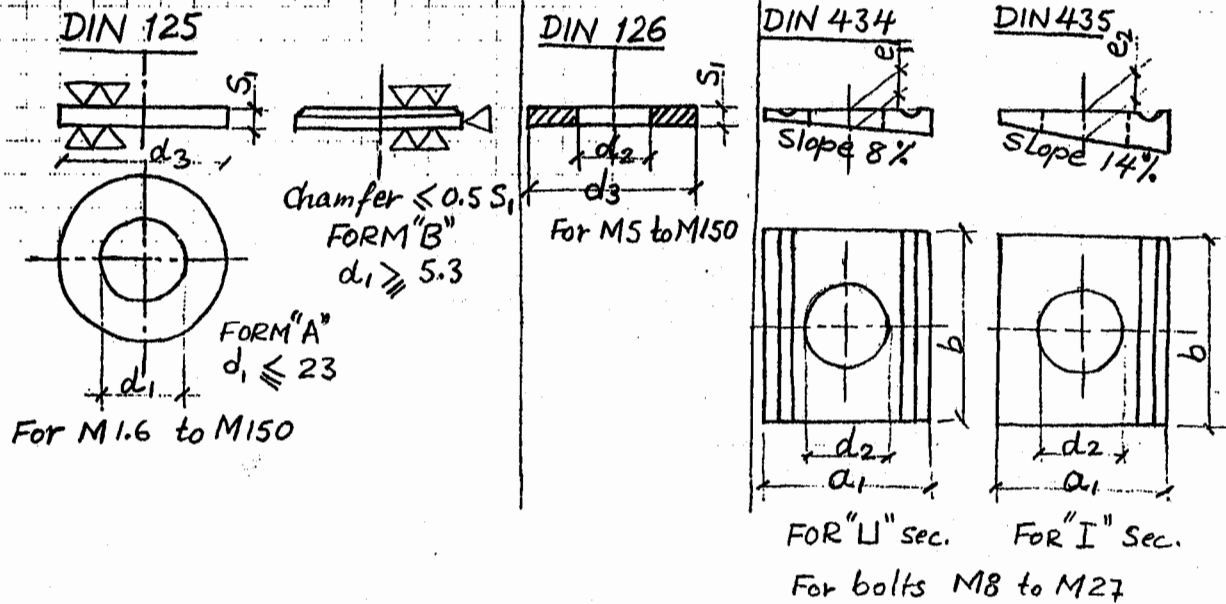
$$\tan \alpha = 0.035$$

$$C_b = 6.754 \times 10^5 \text{ N/mm}$$

$$C_J = 44.4 \times 10^5 \text{ N/mm}$$

$$P_i = 14.8 \text{ kN}$$

19/25

Washers

d_1	d_2	d_3	a_1	b	e_1	e_2	S_1	Bolt diam.
3.2		7					0.5	3
3.7		8					0.5	3.5
4.3		9					0.8	4
5.3	5.5	10					1	5
6.4	6.6	12.5					1.6	6
7.4		14					1.6	7
8.4	9	17	22	22	2.9	3.05	1.6	8
10.5	11	21	22	22	2.9	3.05	2	10
13	14	24	30	26	4	4	2.5	12
17	18	30	36	32	4.5	5	3	16
21	22	37	44	40	5	6	3	20
23	24	39	50	44			3	22
25	26	44	56	56	6	7	4	24
28	30	50	56	56			4	27
31	33	56	62	62	6.5	7.5	4	30

$$\text{Tightening Torque} = T_1 + T_2$$

$$T_1 = 14.8 \left(\frac{11.414}{2} \right) \left[\frac{0.035 + 0.23}{1 - 0.23 \times 0.035} \right] -$$

$$\therefore T_1 = 22.383 \text{ kN.m}$$

$$T_2 = P_a \frac{d_{m_{\text{seat}}}}{2} \cdot \mu_{\text{seat}}$$

$$= 14.8 \left[\frac{22 + 13}{2 \times 2} \right] \times 0.2 = 25.9 \text{ kN.m}$$

$$T = 22.383 + 25.9 = 48.283 \text{ kN.m}$$

$$\sigma = \frac{14.8 \times 10^3}{92.1} = 160.7 \text{ N/mm}^2$$

$$\tau = \frac{16 \times 22.383 \times 10^3}{\pi (10.83)^3} = 89.74 \text{ N/mm}^2$$

$$\tau_{\text{comb}} = \frac{1}{2} \sqrt{(160.7)^2 + 4(89.74)^2} = 120.5 \text{ N/mm}^2$$

$$\tau_y = 120.5 \times 1.3 = 156.6 \text{ N/mm}^2$$

$$\sigma_y = \frac{\tau_y}{0.6} \geq 261 \text{ N/mm}^2$$

Select high tensile steel grade 8.8

Notes:

1- The high tensile steel bolts grade 8.8 is the commercially used grade. Other grades when specified, either of lower or higher grades, are considered special order and will be more expensive.

2- The tightening torque of 22.4 kN.m (23 kgm) is used for all the bolts for the sake of unification.

20/25

$$P_{ax} = 14.8 \text{ kN}$$

$$\mu' = 0.23$$

$$\tan \alpha = 0.035$$

$$T_1 = 22.383 \text{ kN.m}$$

$$T_2 = 25.9 \text{ kN.m}$$

$$T = 48.3 \text{ kN.m}$$

$$\sigma = 160.7 \text{ N/mm}^2$$

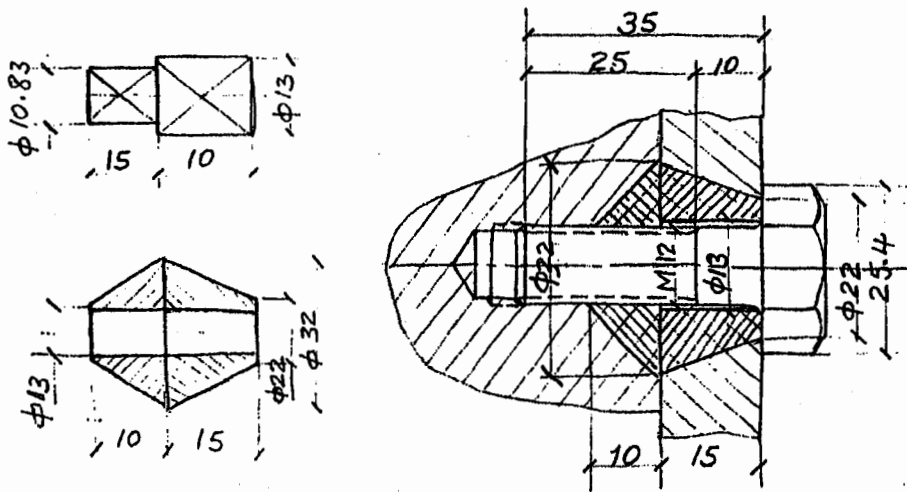
$$\tau = 89.74 \text{ N/mm}^2$$

$$\tau_{\text{comb}} = 120.5 \text{ N/mm}^2$$

$$\sigma_y \geq 261 \text{ N/mm}^2$$

Material
h.t. bolts 8.8

5-2) At "B" and "O":



$$\frac{1}{C_b} = \frac{4}{\pi E} \left[\frac{10}{(13)^2} + \frac{15}{(10.83)^2} \right]$$

$$C_b = 8.82 \times 10^5 \text{ N/mm}$$

$$\frac{1}{C_j} = \frac{4}{\pi E} \left[\frac{15}{\left(\frac{22+32}{2}\right)^2 - 13^2} + \frac{10}{\left(\frac{13+32}{2}\right)^2 - 13^2} \right]$$

$$C_j = 29.22 \times 10^5 \text{ N/mm}$$

Plotting the characteristic lines of bolt and joint, one can find:

Since max load on bolt = $P_{i_{ax}}^0 + P_r = 10.51 \text{ kN}$
where $P_r = 2.5 \text{ kN}$

$$\therefore P_i = 4.5 \text{ kN}$$

$$T_1 = 4.5 \left[\frac{11.414}{2} \left(\frac{0.035 + 0.23}{1 - (0.23 \times 0.035)} \right) \right] \approx 6.81 \text{ kN}\cdot\text{mm}$$

$$T_2 = 4.5 \left[\frac{22+13}{2 \times 2} \right] (0.2) = 7.875 \text{ kN}\cdot\text{mm}$$

Tightening torque = 14.685 kN·mm

For wrench arm = 300 mm

$$\therefore \text{human effort} = 48.95 \text{ N } (\approx 5 \text{ kg})$$

21/25

$$R_{x_{III}}^0 = 48.06 \text{ kN}$$

$$P_{i_{ax}}^0 = 8.01 \text{ kN}$$

$$P_r = 0.3 P_e \\ \approx 2.5 \text{ kN}$$

$$C_b = 8.82 \times 10^5 \\ \text{N/mm}$$

$$C_j = 29.22 \times 10^5 \\ \text{N/mm}$$

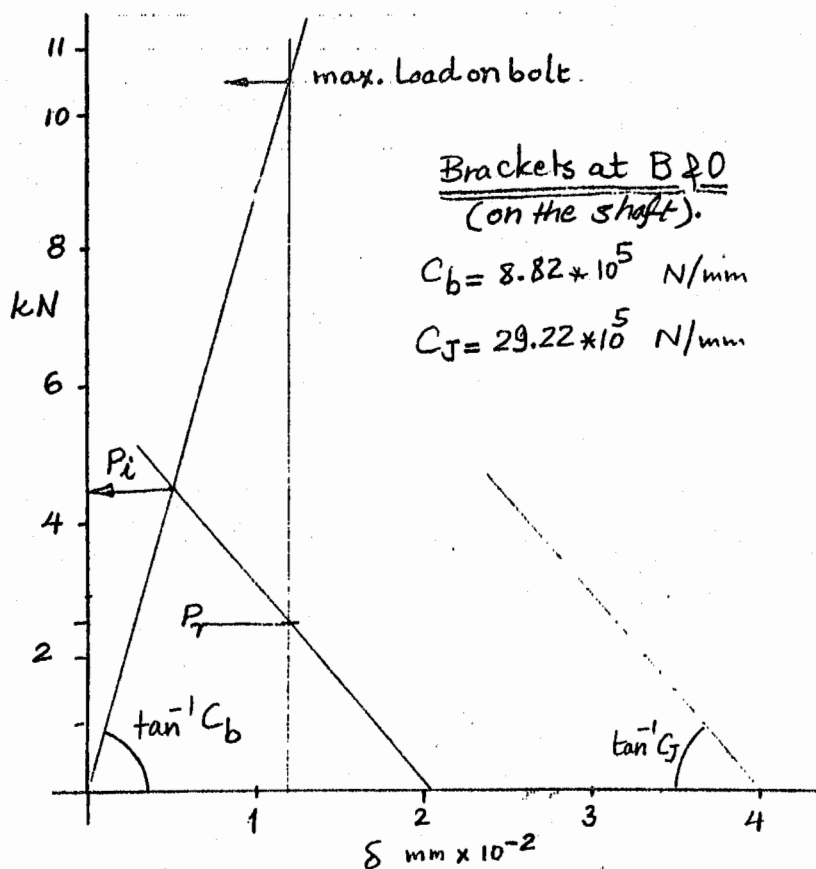
$$P_i = 4.5 \text{ kN}$$

$$\frac{\mu}{\cos \beta} = \frac{0.2}{\cos 30^\circ} \\ = 0.23$$

$$T_1 = 6.81 \text{ kN}\cdot\text{mm}$$

$$T \approx 15 \text{ kN}\cdot\text{mm}$$

22/25



Assembly state of stress:

$$P_{\text{axial}} = 4.5 \text{ kN}, T_1 = 6.81 \text{ kN}\cdot\text{mm}$$

$$\therefore \sigma = \frac{4500}{92.1} = 48.86 \text{ N/mm}^2$$

$$\tau = \frac{16 \times 6810}{\pi (10.83)^3} = 27.3 \text{ N/mm}^2$$

$$\tau_{\text{comb}} = \frac{1}{2} \sqrt{(48.86)^2 + 4(27.3)^2} = 36.6 \text{ N/mm}^2$$

Working state of max. stress:

$$P_{\text{axial}} = 10.5 \text{ kN}$$

$$\sigma_t = \frac{10.5 \times 10^3}{92.1} = 114 \text{ N/mm}^2$$

$$\sigma_y > 114 \times 1.3 \geq 148 \text{ N/mm}^2$$

Assembly stress

$$P_{\text{axial}} = 4.5 \text{ kN}$$

$$T_1 = 6.81 \text{ kN}\cdot\text{mm}$$

$$\sigma = 48.86 \text{ N/mm}^2$$

$$\tau = 27.3 \text{ N/mm}^2$$

$$\tau_{\text{comb}} = 36.6 \text{ N/mm}^2$$

Working stress

$$\sigma_t = 114 \text{ N/mm}^2$$

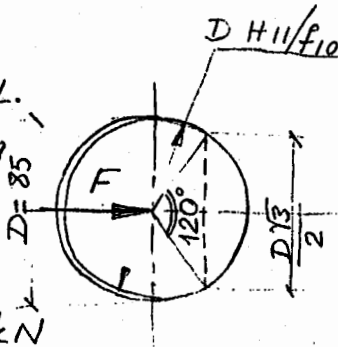
$$\sigma_y \geq 148 \text{ N/mm}^2$$

23/25

6- Post ends and wall brackets:

6-1) Top end bearing :-

During test, test load = 1.2 S.W.L.
will result in crushing the bearing bush. Check for bearing pressure should be based on S.W.L. i.e. for a load = $\frac{36.05}{1.2} = 30.04 \text{ kN}$



$$85 H_{11} = 85^{+0.220}_{-0.000}$$

$$85 f_{10} = 85^{+0.036}_{-0.176}$$

$$l = 100 \text{ mm}$$

$$F = 30.04 \text{ kN}$$

$$p = \text{Bearing pressure} = \frac{30.04 \times 10^3 \times 2}{100 \times 85 \times 1.732} = 4.1 \text{ N/mm}^2$$

$$p = 4.1 \text{ N/mm}^2$$

The bush material is selected to be gray C.I. which has an allowable bearing pressure of 12 N/mm^2 . i.e. the bush will have an extended life.

Material
Gray C.I.

Radial: 6-2) lower end bearings :-

$$F = 30.04 \text{ kN}$$

radial

$$D = 85 H_{11}/f_{10} \text{ also}$$

$$l = 80 \text{ mm.}$$

$$\text{Bearing pressure} = \frac{30.04 \times 10^3 \times 2}{85 \times 85 \times 1.732} = 4.8 \text{ N/mm}^2$$

$$F = 30.04 \text{ kN}$$

$$D = 85 \text{ mm}$$

$$l = 80 \text{ mm}$$

$$p = 4.8 \text{ N/mm}^2$$

The bush material is gray C.I.

$$\text{Axial: } F_{\text{axial}} = 18/1.2 = 15 \text{ kN (= S.W.L.)}$$

$$\text{Total axial load} = 2 \times 15 \text{ kN}$$

$$\text{Disc dims.: } D = 80 \text{ mm, } d = 20, h = 20 \text{ mm}$$

$$\text{Bearing pressure} = \frac{2 \times 15 \times 10^3}{\frac{\pi}{4} (80^2 - 20^2)} = 6.36 \text{ N/mm}^2$$

$$F_{\text{axial}} = 30 \text{ kN}$$

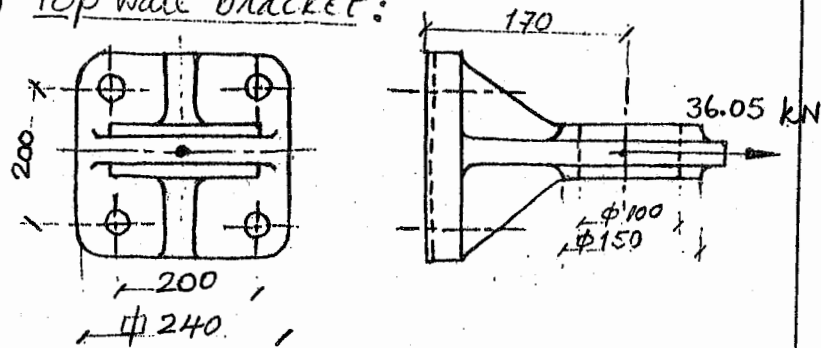
$$D = 80 \text{ mm}$$

$$d = 20 \text{ mm}$$

$$p = 6.36 \text{ N/mm}^2$$

Disc material is selected as gray C.I. 274.

Material
Gray C.I.

6-3) Top wall bracket:

The maximum force acting at B, is 36.05 kN.

The bracket is bolted by 4 bolts, i.e. the force per bolt = $\frac{36.05}{4} = 9.01$ kN.

This load/bolt together with a residual load is estimated to be 14.8 kN ($P_{res} \approx 5.8$ kN which is more than 60%) and the tightening torque will be taken 48.3 N.m. for a bolt size M12x1.25 whose material is H.T.S. grade 8.8.

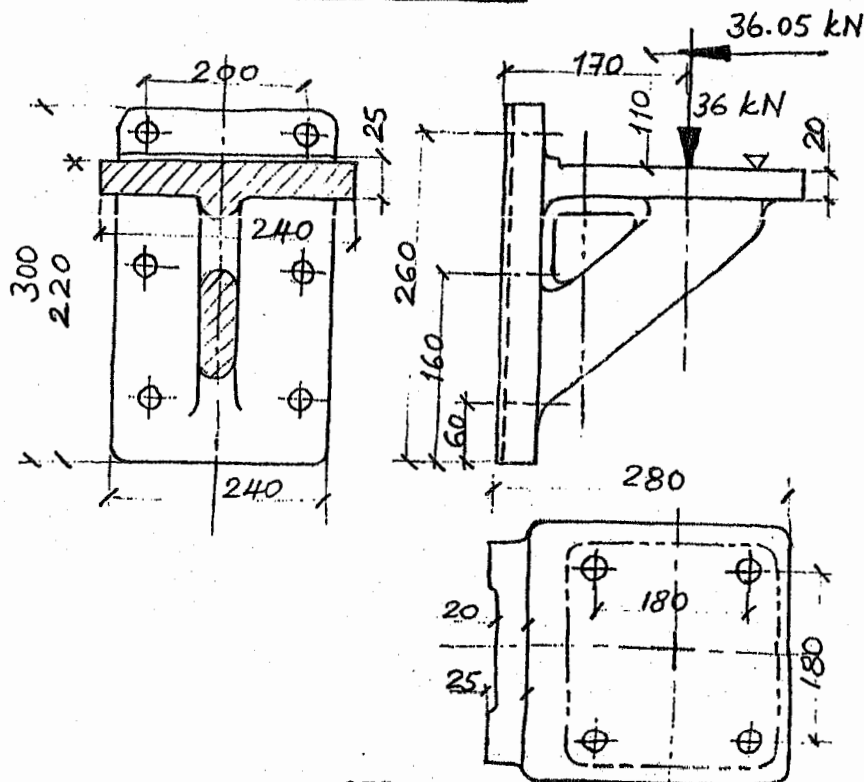
Force/bolt
= 9 kN

$P_{ex} + P_T = 14.8$ kN

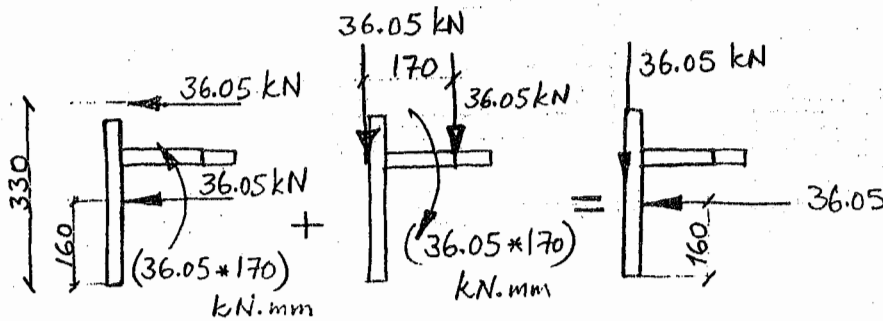
Bolt size M12x1.25

$T = 48.3$ N.m.

Bolt material
H.T.S. Grade 8.8

6-4) Lower wall bracket:

$R_{O_1} = 36.05$ kN



One can see that there is no moment acting on the bracket. If we use the same bolts $M12 \times 1.25$ of grade 8.8 tightened with $T = 48.3 \text{ N.m}$, the axial force in each of the six bolts = 14.8 kN
 \therefore The total force pressing the bracket to the wall is given by

$$P_{\text{tot test}} = 6 * 14.8 + 36.05 = 124.85 \text{ kN}$$

also

$$P_{\text{tot working}} = 6 * 14.8 + 30 = 118.8 \text{ kN}$$

for $\mu_{\text{st/st}} = 0.15$ (min. value for dry friction)

$$\therefore \text{Limit of friction force} = \mu P_{\text{tot test}} = 0.15 * 124.85 = 18.73 \text{ kN}$$

Required vertical resisting force = 36.05 kN

\therefore A shear plate (or dowel pin if possible) is needed to resist a min force of: $36.05 - 18.73 = 17.32 \text{ kN}$

Note:

It is possible to use a friction material of a very thin thickness on condition that the friction coefficient $\geq \frac{36.05}{124.85} * 1.2 \geq 0.35$

The 1.2 factor is a security factor.

However, in a lifting equipment, a positive & not passive means (like friction) are recommended.

6 bolts

$M12 \times 1.25$

$T = 48.3$

Grade 8.8

$$P_{\text{tot test}} = 124.85 \text{ kN}$$

$$P_{\text{tot working}} = 118.8 \text{ kN}$$

$$\mu = 0.15$$

$$\mu_{\text{required}} \geq 0.35$$